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by

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SEA ICE DATA USERS AND THEIR NEEDS

There are two distinct groups which have interests in and would benefit from an expanded understanding of ice conditions in Alaskan waters. The first group consists of those vessel, platform and harbor operators working in or near ice-covered waters who, consequently, are concerned with real-time observations and relatively short-term forecasts of ice conditions. The second group consists of those who are concerned with long-term, or climatological, conditions, whose interests could be termed philosophical or strategic rather than operational.

In terms of the number of vessels and people involved and the areal extent of their activities, the principal operational user group is the fisheries fleet which works the waters of lower Cook Inlet, the Gulf of Alaska and much of the Bering Sea. Dutch Harbor is the second largest fishing port in the US, and fourth in the world, in terms of quantities landed. There are approximately 10,000 individual vessels involved with this harvest, which was worth about $1.2 billion wholesale in the Alaskan economy in 1979. This annual harvest will grow in size and value during the next decade. The total catch from Alaskan waters in 1979 was nearly triple this amount, the balance presently going to foreign operators. The vessels used are relatively small catcher boats which operate out of home ports for a few days or up to one or two weeks at a time, then return their harvest to a port-based processing facility. They are not constructed to withstand pressure within the ice pack and as a consequence remain outside any significant ice concentrations. Because of the proximity of their home ports there will probably never be large-scale, coordinated Alaskan operations centering on factory ships laying-to within the edge of the Bering Sea pack ice, such as those accomplished by Japanese and Soviet fishing fleets which are operating far from their home waters. However, the future develop-

ment and growth of the Alaskan fishery is not entirely clear at this time. While there has been rapid growth in the size of the US fishing fleet and in the size and value of the harvest during the period from 1976 through 1979, most of the latter has been through the activities of foreign vessels as a result of a lack of American crews, processing facilities and a home market. Early in 1980, processing plants within the state were storing tens of millions of dollars worth of unsold products, much of it originally intended for foreign consumption. Nevertheless, since the inauguration of the 200-mile fisheries control zone legislation, the US fishing industry has not yet had an opportunity to develop its capacity to accommodate the Alaskan harvest to the extent anticipated. Consequently, it will probably be several years before appreciably larger numbers of US vessels begin working Alaskan waters, although it is safe to assume that ultimately they will.

Since most of the Alaskan vessels are individually owned and operated they are crewed with a minimum number of personnel and communications equipment. Once sea their sole link with their port is by voice radio, and reports concerning weather and sea ice conditions must by transmitted by such a link. The likelihood of their utilizing more sophisticated, and expensive, equipment is small. For the foreseeable future it may be assumed that the Alaskan fleet will consist of a slowly-growing number of small vessels, operating independently, which maintain contact only occasionally on a voice link with their home port. As long as reasonable harvesting practices are maintained so that the fishery is not depleted, they will continue to operate outside the ice edge in the Bering Sea, or at most in waters with 2 to 3/10s ice cover.

Although there are two distinct types of fisheries concerned, pelagic and bottom--both for flat fish and shell fish--both are limited by the presence of ice. Where trawl lines are concerned, nets are not sufficiently strong to cope

with any ice when they are retrieved nor are tow cables capable of withstanding the abrasive action of movement through anything but the thinnest and youngest ice. When shell fish are sought the floats or buoys which mark the location of the pots are subject to loss by the abrading action of floes, and even were this not the case, the ability to locate the markers within a field of floes is significantly reduced. Consequently, until such time as the ancillary fishing gear is sufficiently strong to withstand the ice forces and sufficiently inexpensive to be affordable to the individual operators they will not penetrate within the edge of the pack, nor set them in places where it will intrude or grow to appreciable thickness.

Perhaps the principal unknown element concerning the foregoing discussion is the lack of knowledge within the US fishing community of the exact nature and distribution of the fish themselves. While it is suspected that the Japanese and Soviet fleets are rather knowledgeable in this matter, the US fleet does not have a reasonable amount of data on the cycles and geographic distribution of the resources which are being sought. With the enactment of the 200-mile fishing zone considerable interest in this matter has been evidenced and more study is being accomplished. The results of these studies will be an enhanced knowledge of the resource and presumably better management of it. While this might mean that new practices may be identified which would call for harvesting within the edges of the pack, the knowledge itself will not necessarily bring about a change in the techniques of the US fleet. Market forces will continue to be the principal determinant of the size and scope of the US effort.

With these considerations in mind, the requirements of the US arctic fishing fleet may be established, as they relate to ice forecasts. Basically, this will amount to a need to know the position of the ice edge, with an accuracy of kilometers or tens of kilometers. Since the equipment available to the

fleet cannot determine the position of individual boats more accurately than this, there is no need for greater accuracy in positioning the ice edge. The critical aspect of this, however, is their need to know the trend of the edge. Is it moving north or south over a given sector, perhaps ten degrees of longitude, and if southerly is it the result of winds or the growth of new ice due to freezing temperatures: if northerly is it from wind action or melting? What is the speed of movement of the edge and what is the tendency for the forthcoming 12- or 24-hour period? These parameters are clearly within the provenance of the marine forecast and are being so handled at present, including development of a computer model at PMEL of ice-edge fluctuations.

Improvements in the accuracy of such forecasts may come through two sources. First, knowledge of the location of the ice edge, within an accuracy of tens of kilometers, at least once every 24 hours and ideally every 12 hours. By and large this cannot be accomplished from existing operational satellite imagery because of limitations of cloud cover and darkness. However, experimental satellites such as SEASAT and GEOS have exhibited a capacity to collect such data regularly under all conditions and future generations of operational platforms will in all likelihood include suitable sensors. These likely sensors also will be capable of locating the ice edge within tens of meters, not just tens of kilometers. As such sensors are of interest to a far larger body than just the Weather Service or the fishing fleet, the decision to fund and opearate them must come from the scientific community as a whole, both within and without the government, and the NWS' role should be to continue to advocate their use and justify it in part from its benefits to the fishing community. The second element for the improvement of ice forecasts lies in the improvement of the marine forecast itself. This in itself is a two-pronged effort, both of which are being actively pursued at the WSFOs in Anchorage and Fairbanks and at

PMEL. Here, the first element is the improvement of the forecast model itself and it is judged that progress is being made to this end at a satisfactory rate. However, the second element is to achieve an increase in the amount of raw data available to the forecaster and the modeler.

By the end of the decade it appears quite logical that satellites will be providing data on wave height, water surface temperature, air temperature, wind speed and direction, ice presence and thickness--at least in steps if not in units--and possibly other parameters with an accuracy which will be a function of the ground truthing established in the experimental stages and the calibrations performed in the operational stages, which accuracy will surpass the requirements of the fishing fleet. In the interim, mention must be made of the possibility of obtaining more data from the boats themselves while they are on station. While this would undoubtedly be of value to forecasters, the spatial and temporal gaps in the input would somewhat limit the value to modelers and climatologists. Further it necessitates an education, and possibly enforcement, program for the operators and a substantial infrastructure leading from the operators to the forecasters. While Japanese operators are required to provide automated weather and position reports under the terms of their licensing agreement such is not the case with US operators.

Because of the spatial distribution and disparate nature of the US operators, an eloquent, specific and irrefutable case must be made setting forth the benefits to them. Should this not be done, with or without a legal stricture, they will probably not expend the effort to comply because it would be viewed as bureaucratic hassling. Were this to happen under penalty of fine, then an enforcement program would blossom by such a magnitude that the bureaucratic hassling would become patently self-evident. Another aspect of this process would be the acccuracy with which the boats could establish their posi-

tion, which would be relatively low, except for the fact that they would tend to cluster thereby giving multiple positions when harvesting from the same or adjacent schools. However, while this low accuracy might be disquieting or inadequate for some purposes the boats themselves do not require high accuracy determination of ice positions for many of their activities. Still another aspect is the organization of the radio feedback network from the boats to the forecaster. It is conceivable that such reports could be passed through a Caost Guard station such as Kodiak for retransmission to NWS but this would require a policy decision among the Federal agencies to ensure appropriate manning levels during the periods in question. Alternatively, boats could report to a commercial shore station, perhaps operated by a fishing association, which could forward the data. From the forecasting point of view the principal drawback to boat reports is that trawling vessels are continually on the move and want data for the area into which they are moving, not for the area from which they have come. For shell fishers this is not as critical because they must spend more time in one "area" retrieving and resetting pots. Since this latter group is more stationary it is desirable to know edge locations to a greater degree of accuracy than trawlers and even to know the movements of patches of ice. For instance in 1979, fishers working Cook Inlet and Shelikof Strait lost pots, traps and associated gear worth approximately $200 thousand--an average, perhaps, of $500 per boat, although not all would be effected. However, until the advent of highly accurate remotely-sensed imagery the only mothod of obtaining adequate data would be by aircraft-borne sensors, including humans, which would necessitate spatial and temporal coverage amounting to several thousand aircraft hours, plus sensor and observer costs which would not be cost-effective.

Inasmuch as ice forecasts are within the scope of NWS's specialized marine

weather forecasts, enhancement of this element of the program would have to be balanced against the needs and priorities of other elements. In order to keep cost increments to a minimum while increasing the utility and accuracy of the forecasts, increasing reliance must be placed on effective technological improvements rather than enlarged human participation. Inclusion of sea state and superstructure icing conditions and probabilities in Alaskan marine forecasts has been extremely valuable to the fishing fleets because these are two parameters which cannot be avoided while at sea; sea ice on the other hand can be avoided, albeit with possible gear loss, until the requisite data are more tractable. However, response to the availability of these data has been such that NWS can take pride in this addition to its service. Unlike some aspects of the specialized agricultural weather forecasts, which have been criticized by GAO as ineffective, the ice services are closely followed, if only because of a virtual total absence of alternate sources of information. Nevertheless, constant contact must be maintained among all interested parties, either through a formal or informal communications infrastructure, to ensure optimum response to user needs. The decade-long efforts of groups such as the Sea Use Council, and its affiliates, highlight the importance of this exchange, for increased technology in itself does not improve a situation without well established interplay and clear channels of communication among informed users and responsible sources.

The second major operational user group in Alaskan waters is cargo shippers. Much fewer in number, they are nevertheless engaged in moving cargoes with dollar values of the same order of magnitude as those handled by the fishing fleet. At this time the northbound cargoes consist principally of barge operators moving cargoes from the conterminous US to Alaskan ports, largely on the west and north coasts, on a once-a-year basis at the time of least ice coverage with standard oceangoing vessels which cannot

sustain ice forces. However, as a result of their decade-long experience in the Beaufort Sea, Crowley Maritime has developed an icebreaking bow, powered by ocean tugs, which can operate in one-year ice and under most circumstances provide adequate convoy for a barge train. Concurrently there is substantial outbound water-borne trade from southern and southeastern ports which is largely in ice-free waters. Conditions in upper Cook Inlet are such that ice is not a problem in the navigation of cargo ships as much as in vessel handling at the berths. However, care must be exercised in the operation of fuel barges in the area but present levels of forecasting are adequate for the amount and types of traffic involved. The situation at Valdez regarding the movement of VLCC tankers is presently a standard traffic situation requiring wind and sea state forecasts. However, the possibility that the Columbia Glacier may begin to calve large quantities of icebergs could necessitate close scrutiny of the movement of these significant hazards to navigation. The tracking of these bergs would become a responsibility of the Coast Guard but they in turn will be desirous of obtaining high-quality forecasts in order that closure of the Valdez shipping route would be minimal.

The requirements of the tug and vessel operators within the next decade are substantially different from those of the fishing fleets in that the former are transiting the ice-covered waters for brief periods on their in- and out-bound voyages rather than sweeping an area along the ice margins for sustained periods. Further, there is a modest amount of latitude in scheduling the arrival and departure of the vessels at their several ports of call. While the Chukchi and Beaufort sea coasts of Alaska are unquestionably ice-infested waters, they almost invariably open for a short period each summer and permit access to north Alaskan terminals for cargo vessels. Unfortunately it has happened that the two seasons, twenty years apart, during which the most massive and valuable convoys were scheduled for north coast resupply

were also the two years in which ice conditions were most severe, with little ice melt and extremely restricted sailing conditions. While these occurrences are useful indicators of the need to improve long-range forecasts, they should not be viewed as indicators of a failure of the forecast system. The state of the art of climate modeling and ice forecasting is such that 6-, 12-, or more months' forecasts are no more accurate than normals, and consequently are of little aid to corporate planners who must develop complex shipping and procurement schedules two or more years in advance.

Under present, and foreseeable, operating circumstances the tug and barge operations to northern and western Alaska require standard marine forecasts, including sea ice conditions and locations, in the format presently utilized by NWS. The nature of the operation also requires that the person in charge of the barge fleet maintain visual contact with the ice within a few hundreds of kilometers of its position and out to the destination. Until the advent of remotely sensed imagery with areal resolution of a kilometer or less under all weather and light conditions this visual scrutiny will be as important to the operators as will detailed ice forecasts.

By the end of the 1980s, there will probably be an inauguration of southbound ship-borne cargoes of petroleum and hard minerals from north and western Alaska. The vessels performing these tasks will be quite different from those presently available. They will be of several hundred thousand dwt capacity, with class 10 structural specifications. Concern over those transporting inert cargoes will not be inordinately great, but those moving crude oil or LNG will capture the attention not only of the operators but of the general public as well. Such vessels will require ice information to an accuracy of tens of meters, not so much to ensure integrity of the vessel as to maintain schedules. Until there is a substantial improvement in the accuracy of ice forecasts, such a requirement means that near-continuous surveillance be maintained

visually from air-borne observation.

The second category of persons interested in sea ice conditions are not really concerned with the receipt of real-time data, but with climatic and long-term averages. Within this category there are two sets of interests. First are the scientific researchers who are attempting to increase knowledge of ice, who also are the principal source of data with which to improve ice forecasts. Second, are the operators of fixed structures in the region of ice-covered waters, which may be harbors, platforms, or artificial islands. Initially their interest is with average and maximum forces which will impinge on their structure in order to develop a reasonably safe, but not excessively expensive design. Once the item is in place they will require standard forecasts to keep abreast of conditions, and plan as best they can for circumstances which were unanticipated.

PRESENT NATIONAL CAPABILITIES

Generally, the magnitude and quality of the US ice observing and forecasting capability is adequate to meet the rational needs and to serve the users described above. This applies to the present user community, but care must be taken to maintain the capability level with growing technological capacities of the 1980s and 1990s.

The Navy-NOAA Joint Ice Center was initially established at the Navy's Fleet Weather Facility, Suitland, Maryland in 1976. This activity was created to meet the anticipated increase in interest in ice-covered waters other than Department of Defense activities. The Center was the logical outcome of the need of the civilian sector for ice data in that it built upon an existing federal capability, to the benefit of both sponsors. It serves as the nexus of the data collection system regarding ice information and is physically located such that the sponsors' systems input are mutually supportive. The principal drawback at present is that the cadre of civilian employees is low, while the military billets are rotated regularly after the custom of the Navy. As the result the degree of experience, while fully competent, is low and it will require several additional years to obtain permanent positions in which the incumbents can gain extensive experience.

Inasmuch as the public has come to expect ready access to Weather Service offices, it was logical for NWS to establish a position for an ice forecaster within the Alaska region following the hazardous navigation season in the summer of 1975. The principal responsibility now lies in the WSFO Fairbanks, for the Bering, Chukchi and Beaufort seas, with appropriate assistance furnished from WSFO Anchorage for upper Cook Inlet or other portions of the Gulf of Alaska in which ice may form during unusually cold seasons. These offices can and do provide information within the state in a fashion which could not be

performed from the far-distant Joint Ice Center.

Near real-time satellite imagery provides the major source for current sea ice data at both the Joint Center and the two WSFO's. The actual data are received at the WSFO's in a more timely fashion than at the Joint Center because of their proximity to the readout facility at Gilmore Creek. Although low key efforts have been and are being made neither the Joint Center nor the Alaska WSFO's yet have real-time access to LANDSAT imagery. Real-time access to coastal station ice reports continues as implemented by the Navy in the 1950s and eminates principally from those stations established as part of the DEW Line. However, Nome and several other NWS coastal stations have discontinued their provision of ice reports. While some efforts have also been made to acquire ship ice reports, these have not been very successful and the respondents are largely confined to Coast Guard icebreakers and occasional reports from Soviet fishing vessels.

Data acquisition from unmanned stations or buoys--extremely valuable in determining sea ice drift--also have met with very little success. This is true in spite of the fact that such unmanned stations or buoys have become relatively inexpensive and their performance has been remarkable in the AIDJEX, OCSEAP and private programs. Indeed NOAA has taken virtually no action to launch a buoy deployment program.

With respect to meteorological data, the extremely satifactory system of Class A weather reporting stations covering coastal Alaska and some of the offshore islands, operated by the weather Bureau DOD in the 1950s, no longer exists as a result of government austerity. Stations of particular importance in this regard which have been discontinued include Wainwright, Northeast Cape and Gambell. Stations such as Oliktok, Lonely, Point Lay and Nunivak if upgraded would constitute a more complete reporting system. Although some of

the aforementioned stations do provide limited reports within the intra-Alaska system they are not received at the Joint Center.

Further, the absence of a program of regularly implanting a network of automatic weather buoys limits the quantity of data available for detailed sea ice forecasts based on sea level pressure and air temperature reports from ocean areas. Pressure and temperature gradients seaward of the coastline are prerequisite to accurate understanding and predictability, particularly in short-range forecasting, of such ice features and processes as: flaw and/or shore lead openings and closings, changes in concentration in extant leads, production of pressure ice and scouring and ice edge and boundary movements. Buoy weather data would also assist in the precise determination of pressure centers and fronts and in forecasting high winds, superstructure icing and conditions pertinent to flight and other operations.

A program to collect hydrographic/oceanographic data for operational support and/or for a systematic, regularly conducted ice observation and forecasting program is virtually non-existent in the coastal waters of Alaska. Fortunately, since the 1950s the Navy, Coast Guard and university activities have conducted sporadic, infrequent surveys, but they have been almost entirely confinced to the largely ice-free navigation season. Exceptions have been Coast Guard's Bering Sea Winter Patrol which only recently operated as far north as the Bering Strait or Chukchi Sea. During the north coast navigation season--and sometimes extending well into freeze-up--scientific surveys have been conducted well into the main pack. The resultant data, because of the diversity of tracks followed as well as their infrequency, has not been sufficient to understand oceanographic variability as it relates to the varying severity of the ice seasons.

During the critical navigation season the warming of the coastal water

masses cannot be determined without sea surface temperatures and temperature profiles. Thus, these variables are prerequisite to the understanding and prediction of the rate of ice melt and decay.

Bathymetric data in these characteristically shallow waters are adequate only over those routes where long-term repeat operations occurred, such as those conducted by the Navy in support of MSC logistic resupply operations. In important areas where drilling may be contemplated or where coastal ridging affects long-term deformational activity--but where operations have not been regularly conducted--data are completely lacking. Also, tidal and river run-off measurement stations near or at the coast are so rare they offer little or no assistance to the ice forecaster in assessing their effects on ice behavior.

From the foregoing, it may be concluded that there presently exists within NOAA the framework and manpower for the preparation and promulgation of sea ice forecasts which fulfill the minimum requirements of the community of users. The system is not as comprehensive as it could be if more funds were available nor is it as large as those of Canada or the Soviet Union. However, in view of the proportional relevance of ice-covered waters to the whole of US marine commerce it is fully sufficient in its scope and operation.

PROGRAM ALTERNATIVES

There are effectively two alternatives between which NOAA can choose concerning a sea ice forecasting capability: maintain the present level of activity or substantially increase it. The latter is inherently a political or policy decision which carries with it very substantial fiscal requirements. However, the political process is concerned not with the preaching and application of doctrines but with the management of prejudices and the reconciling of interests, and the level of involvement must be established by the appropriate management entity. It is conceivable that the US government simply opt out of the ice forecasting activity and leave it to the private sector to perform such tasks as the market demands. This does not appear to be a viable alternative, however, because of the internal, statutory requirements of several federal agencies, such as the Coast Guard and the Environmental Protection Agency, for such information in the performance of their functions.

Of the two alternatives, the first is to maintain the present pattern and level of activity. As has already been initiated at the Joint Ice Center, this pattern requires the increasing utilization of man-machine interactive capabilities for processing and analyzing ice data. It is unrealistic to consider or to finance a man-power-heavy function of this sort in the present and foreseeable financial situation. The implementation of the AFOS program will materially assist in the dissemination of pertinent information among geographically removed centers. By following such a course, NWS will be able to provide WSFOs and all interested users with state-of-the-art forecasts. As long as plans develop to slowly enlarge the civilian, long-term, staff of the Center at pace commensurate with the development of remote sensing hardware and interactive computer storage of data NOAA will fulfill its responsibility to the public.

The second alternative is for NOAA to undertake the provision of a greatly expanded ice information and prediction system, and effectively operate its own national (civilian) ice prediction center. The minimal number of professional sea ice forecasters for such an activity is considered to be four and this group must be augmented with a technical group of at least eight, but preferably ten. These technicians would be trained and selected to perform the following functions: ice observing including such field work as aerial, shipboard, and coastal station and manned ice station data collection, encoding and transmission. When not engaged in field activities they would be acting as interpreters of remote sensor data, compiling sea ice charts and statistical data related to sea ice; in general they would function to assist the sea ice forecaster, tasks which are currently performed by Navy personnel. The ice prediction activity could be relegated to a much less vital role than is now the case. On the other hand significant advantages would result from the suggested option. Field functions would be performed on a temporary duty assigned basis as operational requirements dictate. Decisions to assign either forecasters, observers or both would depend upon user requirements. This arrangement, to an unprecedented degree within NOAA, would permit both types of specialists to acquire invaluable familiarity and experience with actual ice conditions in the varied Alaskan regimes, with communication and operational problems existing at field stations and between those stations and the national center and finally to better transfer experience and knowledge gained to other national center personnel. Possible sites and duty stations of the type just described include Barrow, Prudhoe Bay, Barter Island, Kotzebue, Nome, King Salmon and Anchorage. In addition, this alternative would contribute materially to qualifying such personnel to serve ultimately as instructors in another necessary ice information program component, a training facility and curriculum.

This alternative would also promote a much more integrated and smooth

mechanism whereby improvements and professionalism in all the system components would be fostered. It further would suggest disassociating present Navy and NOAA functions, as they are not particularly compatible from an operational point of view. Thus, in the present case of a highly limited number of experienced and trained specialists, the Navy would be completely free to devote all its available talent to its DOD requirements, many of them sensitive; NOAA could much more effectively respond to the non-DOD users and needs. Any stresses stemming from the combined use of military and civilian personnel for differing tasks would be largely eliminated and any inherent dilution of effectiveness through attempting to accomplish these diverse tasks would be eliminated.

Another option, which is not given much credence, is for NOAA to divest itself of in-house ice forecasting activity and contract the work to the private sector. Not only is this out of keeping with virtually all federal practices, it ignores the potential need of the government for data which might otherwise be unobtainable or unavailable. There is unquestionably a requirement within the Navy for ice forecasts and their activity will continue. For NOAA to relinquish its participation in this field it would subvert the mandates given it for the performance of the specialized marine weather service forecasts.

RECOMMENDATIONS

It is tempting, and perhaps too common, to permit past achievements to furnish the goals for future actions. There was a point in time when virtually all the US ice forecasting capability was accomplished by the federal government, in particular by the Navy for its own ends. Subsequent developments have broadened the circle of interest in this activity, but in parallel with this have been gradual shifts in federal policy. Over the past two decades the government, and NOAA specifically, has recognized its limits to satisfy the needs of all users of weather information and data and now actively maintains a policy of encouraging the development and maintenance of a strong private (industrial) sector of meteorology and climatology. At the same time NOAA does have a statutory responsibility to furnish specialized marine forecasts. However, examination of the users of ice forecasts and the benefits accruing to them from improved accuracy of the forecasts leads to the conclusion that these users are really special cases which can achieve the desired ends through some means other than increased federal participation.

In the case of the fishing industry, they must simply operate at the outer edges of the ice pack as they have always done. Before this industry will be in a position to benefit from more frequent and more accurate forecasts, significant advances must be made in understanding the ecology, and more particularly the geography, of the organisms being harvested. Also, there must be changes in the market economy which will permit vessels, catching gear and equipment to work within the boundary of an appreciable concentration, perhaps 3/ to 4/10s, of ice. Furthermore, high-efficiency (and costly) navigation gear must be installed and manned on the vessels. Whether or not market forces will permit such a return on the harvest is uncertain at best.

In the case of the resource extraction industry, their needs are so

special that it is only realistic to assume that they should bear the burden of the cost themselves. As the nature of the commodities carries significant likelihood of return on investment to the developers, the attainment of this aspect of exploiting the resource is as much a part of development cost as is seismic exploration. The ultimate user of the resource will, of course, bear the costs attendant to its development but there is no clear reason why this should be done by the federal government through the tax structure rather than directly through the resource concerned. In this respect it is of interest to note the activity of the Canadian government which has jurisdiction over a far more geographically complex body of arctic waters. As their military requirements are not as paramount as in the US, all of their forecasting activity is located within civil departments. Staffed by nearly two dozen professionals and a like number of technicians they have relied heavily on aircraft surveillance of their ice-covered waters because of the need for large-scale, detailed presentation of the many small channels utilized by commercial and government traffic. Three patrol aircraft are chartered annually for a minimum of 2,400 flying hours. However, when the occasion arose to develop a forecast program in support of the oil and gas exploration in the Canadian arctic, it was decided that industry should support the effort, albeit with government personnel. Over 120 man-years effort were used to develop a computerized forecast system and operate on a (hurried) trail basis. While it was reasonably satisfactory to the users, the government has terminated its participation in the program because of the press of other responsibilities on its manpower.

The prudent, and legal, responsibilities lying on those who develop arctic resources are such that the designs contemplated and utilized must take account of the worst conceivable situation. In these circumstances the variations of less-than-worse conditions are not as critical as they might otherwise be. Con-

sequently, the principal users of federal ice forecasts are those agencies which will bear the responsibility for monitoring disasters and tragedies engendered by those who are working in ice-covered waters. While such events are still in the rather distant future it behooves NOAA to sustain its capacity to forecast ice conditions and to retain within its structure a framework which ensures continuity of personnel and effort at a level commensurate with the pace of technological development.

BIBLIOGRAPHY

Agnew, T., 1977. Prediction of representative surface winds in the Beaufort Sea computerized support system. Downsview, ON: Fisheries and Environment Canada. Atmospheric Environment Service Technical Memoranda TEC 851. 30 p.

Albery, Pullerits, Dickson & Associates, 1978. Marine transportation of oil and LNG from the arctic islands to southern markets. Toronto, ON: Report to Strategic Studies Branch, Transport Canada. 4 vols.

Bourque, D.A., 1979. The C.P.S.S. (Beaufort-type): A description. Toronto, ON: Unpublished ms. 20 p.

Carsey, F., 1977. Coastal meteorology of the Alaskan arctic coast. Boulder, CO: Env. Res. Labs. Annual Report RU519. OCSEAP Arctic Project.

Clodman, P., and F.B. Muller, 1975. Real-time environmental prediction system. Victoria, BC: Dept. of the Environment. Beaufort Sea Technical Report #20. 138 p.

Environmental Research Laboratories, 1978. Interim synthesis report: Beaufort/Chukchi. Boulder, CO: National Oceanic and Atmospheric Administration. 100 p.

Ganong, W.F., 1978. What constitutes a modern ice information service? The Marine Observer, 48; 259: 34-37.

Global Marine Engineering Co., 1978. A preliminary feasibility study of a tanker transportation system serving the northwest coast of Alaska. Newport Beach, CA: Global Marine Eng. Co. Final report - Executive summary (Part 1 of 3), to US Department of Commerce. Prepared by M. Halebsky, M. Lebovits, R.M. Romley. 39 p.

Godin, Raymond H., 1978. Data sources and sea ice products of Fleet Weather Facility/Joint Ice Center, Suitland. Suitland, MD: US Navy Fleet Weather Facility/Joint Ice Center. 10 p.

Hibler, W.D., 1978. A dynamic thermodynamic sea ice model for climatic studies. Hanover, NH: US Army Cold Regions Research Engineering Laboratory. 57 p. Manuscript submitted to J. Phys. Oceano.

Hunt, W., and C.M. Naska, 1978. A baseline study of historic ice conditions in the Beaufort Sea, Chukchi Sea and Bering Strait. Boulder, CO: Environmental Research Laboratories. Final Report. Research Unit 261. OCSEAP Arctic Project.

Levine, Z., and A.O. Winall, 1978. Conceptual design of a nuclear-powered ice-breaking tanker transportation system. Philadelphia, PA. Prepared for presentation at the Society of Naval Architects and Marine Engineers. Unpublished ms. 41 p.

McQuillan, A.K., and D.J. Clough, 1973. Benefits of remote sensing of sea ice. Ottawa, ON: Dept. of Energy, Mines and Resources. Research Report 73-3. 29 p.

BIBLIOGRAPHY

Nagler, R.G., and A.C. Schultheis, 1979. Polar environmental monitoring. Arlington, VA: System Planning Corp. Final Report to NASA under contract JPL 955068. 94 p.

NORCOR, 1978. A study of ice conditions along marine shipping routes in the Arctic Archipelago. St. John's, NF: NORCOR Engineering and Research Ltd. Report to Strategic Studies Branch, Ministry of Transports. 96 p.

Sea Use Marine Services Development Group, 1976. Improvement of marine advisories and optimum track ship routings. Seattle, WA: Sea Use Foundation. Final Report for 15 July 1974-31 January 1976, SEA USE 1-76 Report to US Dept. of Commerce. Vol. 1. 65 p.

Sea Use Marine Services Development Group, 1977. Support of the Seattle Ocean Services unit in fiscal year 1977. Seattle, WA: Sea Use Fdn. SEA USE 2-77 Report to US Dept. of Commerce. Vol. 1. 30 p.

Sea Use Marine Services Development Group, 1978. Support of the Seattle Ocean Services unit in fiscal year 1978. Seattle, WA: Sea Use Fdn. SEA USE 1-78 Report to US Dept. of Commerce. 37 p.

State of Alaska, 1978. The Alaska economic information and reporting system. Juneau, AK: Alaska Division of Economic Enterprise. Quarterly report, October 1978. 25 p.

State of Alaska, 1978. The performance report of the Alaska economy in 1978. Juneau, AK: Alaska Division of Economic Enterprise. Vol. 7. 107 p.

State of Alaska, 1979. The Alaska economic information and reporting system. Juneau, AK: Alaska Division of Economic Enterprise. Quarterly report, January 1979. 25 p.

State of Alaska, 1979. The Alaska economic information and reporting system. Juneau, AK: Alaska Division of Economic Enterprise. Quarterly report, April 1979. 25 p.

Tussing, A.R., 1978. Implications of oil and gas development for Alaska. Burnaby, BC: Simon Fraser University. Prepared for a Symposium on H.A. Innis. Unpublished ms. 18 p.

Tussing, A.R., and C.C. Barlow, 1978. An introduction to the gas industry with special reference to the proposed Alaska Highway gas pipeline (A preliminary report to the Alaska state legislature) and Marketing and financing supplemental gas: the outlook for, and federal policy regarding, synthetic gas, LNG and Alaska natural gas. Anchorage, AK: Institute of Social and Economic Research, University of Alaska. I-115 p., II-170 p.

Tussing, A.R., and C.C. Barlow, 1979. The Alaska Highway gas pipeline: a look at the current impasse. Anchorage, AK: Inst. of Soc. and Econ. Res., U. of Alaska. A report to the Alaska state legislature. 72 p.